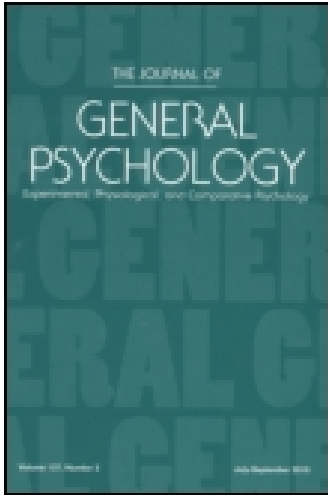




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THE RATE OF ESTABLISHMENT OF A DISCRIMINATION*

From the Laboratory of General Physiology of Harvard University

B. F. SKINNER¹

I

One characteristic of the process of conditioning is its marked tendency toward generalization or spread. When a conditioned reflex is first established, all the properties of the newly conditioned stimulus are not essential in eliciting the response. Stimuli in which some of these properties are absent or replaced by others may be effective. But if only one property of the stimulus is experimentally correlated with the occurrence of the unconditioned or previously conditioned reflex upon which the conditioning is based, the response to a stimulus lacking this property is, of course, not reinforced. In such a case the organism eventually comes to respond to stimuli possessing the distinguishing property but not to respond to those lacking it. The process through which this is brought about is called discrimination.

In a discrimination we are concerned with at least two stimuli, S_1 and S_2 , which possess properties in common but also differ from each other in some significant way. Two tones differing in pitch, two lights differing in intensity, or two groups of stimuli differing with respect to one or more of their members are typical examples. In establishing a discrimination both stimuli are first conditioned to elicit a common response (R). Subsequently the response is reinforced when elicited by S_1 , but is not reinforced when elicited by S_2 , so that the reflex S_1-R remains conditioned, while the reflex S_2-R declines in strength and eventually disappears. Technically the process of discrimination thus consists of the continued conditioning of one reflex and the concurrent extinction of another, where the two reflexes are related through properties of their stimuli (and through a common response). The phenomenon as observed is

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therefore only a special case of extinction, and no separate treatment would be required if the extinction and the continued conditioning could proceed independently. But this is not the case. The reinforcement of S_1-R affects the strength of S_2-R also, and there is a converse sharing of the extinction. The extent of the mutual interference is probably determined by the degree of community of the properties of the two stimuli.

It will be convenient to regard all such pairs of stimuli as constituting a series, in which the order is determined by the degree to which the members of a pair possess their properties in common. At one end of such a series the two stimuli in a pair are practically identical and the mutual interference is very great. In the limiting case we are in fact dealing with essentially only one stimulus, the response to which we sometimes reinforce and sometimes do not, and no discrimination is possible. At the other end of the series the two stimuli possess no significant property in common, and the two reflexes are virtually independent. Consequently the processes of conditioning and extinction may go on without interference, and in such a case the term "discrimination" is not used.

Most experiments involving discrimination are concerned with locating the upper limit of such a series within a given sensory field. That is to say, they attempt to evaluate the least differences between stimuli discriminable by the organism. They are directed toward the measurement of a sort of capacity, which may be either sensory or central. The process of discrimination enters into such an experiment only as part of its method, and no further inquiry is made into the process itself than is necessary in obtaining some convenient indication of its completion. In the present paper, however, we shall not be concerned with the capacity of the organism to form a discrimination. The stimuli to be used show relatively gross differences, and each pair would lie only midway along the series. Our main object is rather to follow the course of the development of a discrimination, and to determine as accurately as possible the properties of the process. In addition, we shall test the hypothesis that, if we are correct in regarding a discrimination as only a special case of extinction, the essential similarity of the two processes should be experimentally verifiable. A large part of each problem is a matter of definition or methodology, but the present paper is confined so far as possible to the report and analysis of experimental material.

The development of a discrimination is observed in any given

case as a change in the strength of the reflex undergoing extinction. It is assumed in the following discussion that the reinforced reflex remains maximally conditioned, or rather that any variation in its strength (which must be slight) may be ignored. The significant change appears in the state of the unreinforced reflex, which progressively declines in strength until it eventually disappears, when the discrimination is said to be complete. During the change the strength of the reflex may be measured by the magnitude of the response to a stimulus of a given constant value, as, for example, in Pavlov's method. The typical "discrimination-box" method uses the prepotency of the reinforced reflex over the unreinforced when the stimuli are presented simultaneously. In the present investigation, however, a third measure is used, namely, the rate at which the response is elicited under continuous stimulation. It has already been used in investigating the processes of conditioning and extinction (5, 6), and if the preceding account is essentially correct it should be adaptable to the present subject-matter.

II

The reflex chosen for the experiment and the conditions under which it is observed have been described elsewhere (4, 5, 6). Four identical sets of the apparatus are operated simultaneously. Each consists of a dark, well-ventilated, sound-proofed box, with inner dimensions of 45 cm. x 36.5 cm. x 23 cm., containing the following devices: (*a*) a compartment from which a rat may be released automatically after the box has been sealed, (*b*) a supply of drinking water, (*c*) a small inverted truncated cone, against one wall, with its upper rim 4.5 cm. from the floor, which serves as a food-tray, and (*d*) above the cone, 9.5 cm. from the floor, parallel to and 1 cm. from the wall, a horizontal bar, made of heavy wire, which may be pressed downward approximately 1.5 cm. against a tension of 10 grams. As the lever moves downward, a mercury switch directly behind the wall is closed. We are concerned with the response of the rat in pressing this lever, which we may define as any movement by the rat which results in the closing of the switch. The switch operates a food-magazine, which discharges a pellet of food of standard size into the tray, where it is accessible to the rat. The connection between the lever and the magazine may be broken at will by the experimenter. Throughout a series of experiments the

rats are fed exclusively with a commercial dog-biscuit. The pellets of food used in the magazine are of the same material.

The movement of the lever, whether or not it is followed by the discharge of food, is recorded in an adjoining room with apparatus previously described (4, 5). The method yields a kymograph record reading *time* on the abscissae and *number of responses to the lever* on the ordinates. Figures 1, 2, 4, 5, 6, 8, 10, 11, 13, 14, 15, 17 are reproduced from photostat copies of such records. In each case coordinates have been added and labeled. In the original records one hour is represented by 8.1 cm. on the time axis. The fairly great reduction in size has made it necessary to retouch the records in some few cases to obtain a clear reproduction. In order to avoid irregular contacts a modified form of the circuit-breaker previously described (3) has been used. The device acts to break the circuit from the lever for a short time following a response—in the present case for approximately two seconds, which does not include the time during which the lever is held down by the rat.

The only additional requirement for the investigation of a discrimination is an extra source of stimulating energy under the control of the experimenter. Two sources—one visual, the other auditory—have been used. The former is a small (3 c.p.) electric bulb placed against the wall considerably above and to the right of the lever. The other is the magnetic latch at the door of the release compartment, which is available, after the release, as a source of stimulation. It gives a clear double click.

This extra stimulating material is used in the following way. The experimenter controls the current to the light and the connection between the lever and magazine in such a way that the response to the lever-plus-light is always followed by the discharge of a pellet of food into the tray, while the response to the lever alone is never so reinforced. The animal eventually "learns to respond to the lever when the light is on but not to respond when the light is off." The stimulation arising from the lever plus that from the light is the S_1 of our paradigm; that from the lever alone is the S_2 . The auditory stimulus is used in the same way, with the following exception. In the case of the light the extra stimulus, presented before the reinforced response, is still present when the response is made, but this is not true of the sound (since it is not continuous). No significant difference has appeared between the results in the two

cases, and the records are considered together in the following discussion.

In order to utilize the rate of elicitation as a measure of the strength of the extinguished reflex, it is necessary to control the temporal conditions of the experiment quite carefully. We shall proceed at once to a description of the present procedure. The reasons for adopting it will be explained after the results have been considered.

III

We have elsewhere described records of the extinction of the response to the lever after small amounts of reconditioning (6). In Figure 1 a series of four curves obtained during a two-hour period is reproduced. The response had been thoroughly extinguished on the preceding day. An extremely slight loss of extinction is evident at the beginning of the present record (at *A*), where the rat makes five scattered responses (unreinforced) during the first 8 minutes. The circuit to the magazine is then closed and the next response (at the vertical mark at *B*) is followed by the discharge of a pellet of food into the food-tray. The magazine is immediately disconnected. After the pellet is eaten the rat begins to press the lever at a high although diminishing rate, and during the next 25 minutes a typical curve for extinction is described. When a low rate of elicitation has been reached, the magazine is again connected (just before *C*) and the next response of the rat is followed by the discharge of a pellet of food. The magazine is then disconnected, and a second curve for

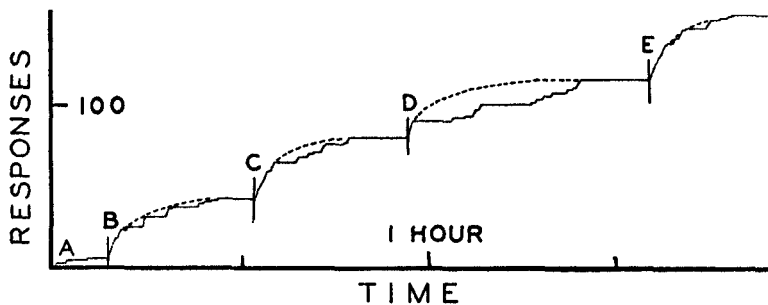


FIGURE 1

EXTINCTION CURVES FOLLOWING THE REINFORCEMENT OF SINGLE RESPONSES

extinction is obtained. The process is repeated at *D* and at *E*. A cyclic variation is apparent in all four curves, and in those at *C* and *D* the experimental curves are depressed considerably below the theoretical. These are typical effects, which have been discussed elsewhere (6).

In Figure 1 each reconditioning is effected when the curve for the previous extinction is practically complete. If the second reconditioning follows more closely upon the first, however, the remainder of the first curve for extinction appears to sum algebraically with the second. If the reconditioning is periodically repeated at some

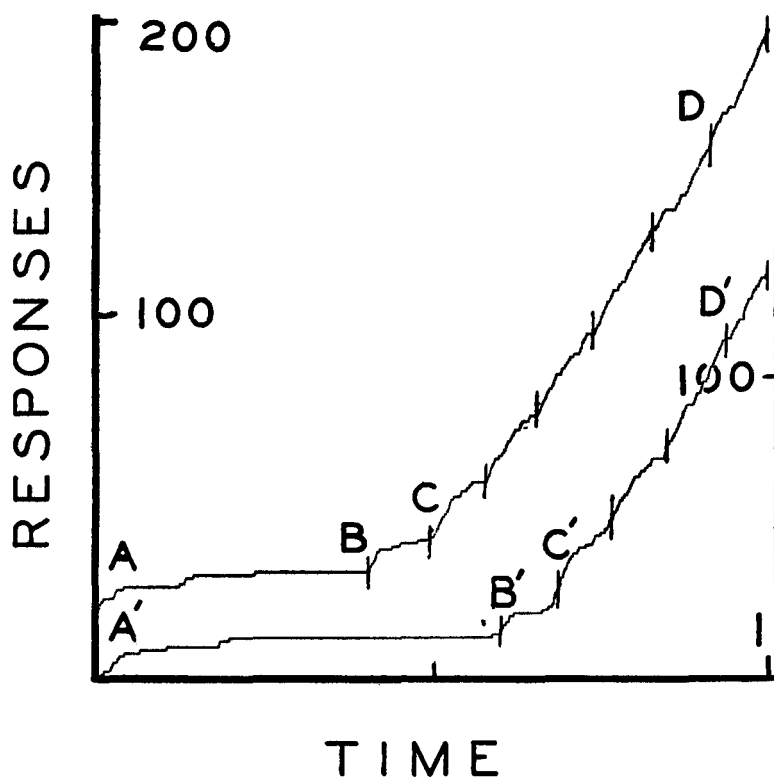


FIGURE 2

FUSION OF SUCCESSIVE EXTINCTION CURVES FOLLOWING THE REINFORCEMENT OF SINGLE RESPONSES (AT B, C, ETC.)

interval shorter than the average effectual length of the extinction curve for the amount of reconditioning employed, the successive curves continue to sum, until eventually a complete fusion takes place and the strength of the reflex remains at a constant value so long as the periodic reconditioning is maintained (for 24 experimental hours in the following experiments).

The development of a fused state is shown in Figure 2. The records are for two rats in which the response had been well extinguished on the preceding day. Some loss of extinction is shown in both cases (at *A*, *A'*), but the rate of elicitation quickly reaches a very low value, which is maintained for approximately 25 and 35 minutes respectively. At *B* and *B'* a schedule of periodic reconditioning is instituted, in which the response to the lever is followed by the delivery of a pellet of food every 5 minutes, and the intervening responses are allowed to go unreinforced. In the figure the reinforced responses have been indicated with vertical bars. The extinction curves at *B* and *B'* have the usual form, if we allow for the difficulty of approximating such a curve with as few as 10 or 12 discrete steps. The curves at *C* and *C'*, however, show much longer rising limbs, which, as we have said, apparently contain the responses remaining to the preceding curves. The third curves have still longer rising limbs, and, as the other reconditionings ensue, the character of each curve is finally lost and the records assume a constant slope. Thereafter the elicitation proceeds at a steady rate, and it is not possible to tell from the recorded behavior where the successive reinforcements occur.

IV

Against such a constant rate the process of discrimination is observed with the present method. The phenomenon is therefore important for our purposes and must be considered in detail. The following conditions of the general procedure may be noted. A special control of hunger is necessary. In experiments upon drive and conditioning reported elsewhere (3, 5) a fairly constant degree of hunger at the beginning of successive daily experiments was obtained with the simple method of feeding the animal once a day at the required hour. The effect of the routine was to develop a hunger cycle which reached its daily peak at the time of the beginning of the experiment. In a study of extinction, however, this condition cannot be fulfilled, since the animal does not receive any

considerable amount of food during the experimental period and must be fed its principal ration afterward. If such an experiment is repeated for several successive days, the peak of the cycle shifts from the time of the beginning to the time of the end of the experimental hour. Evidence for the shift may be obtained independently from a study of the spontaneous activity of the rat, using a method described elsewhere (7). In order to eliminate the shift, the present experiments were conducted on alternate days only, and on the intervening days the animals were fed in their living-cages at the beginning of the hour of the experiment. The intervening days are neglected in the following discussion, where such a phrase as "the preceding day" must always be understood to mean the preceding experimental day, with an intervening non-experimental day omitted.

In the first experiment to be considered four different intervals were interposed between successive reconditionings, namely, 3, 6, 9, and 12 minutes. These were assigned to four male rats, P7, P9, P8, and P10 respectively, aged 106 days at the beginning of the experiment. Since it is not possible to obtain the elicitation of a response immediately after the magazine has been turned on, the intervals cannot be exactly determined. In the present case the delay was added to the interval, and the resulting average intervals for the series were 3 minutes 6 seconds, 6 minutes 27 seconds, 9 minutes 47 seconds, and 12 minutes 59 seconds, respectively. In the other experiments to be described it was deducted from the succeeding interval, so that the average was exactly of the scheduled length.

Prior to this series of observations the response to the lever had been conditioned² and extinguished. Each animal was placed in its box at the same hour daily (9:00 A.M.) and approximately two minutes later was released into the main part of the box, where the lever was accessible. The first response to the lever was reinforced, and thereafter single responses were reinforced according to schedule. All responses to the lever, whether reinforced or not, were recorded. A characteristic constant rate of elicitation was attained in each case. The animals were removed from the boxes at the end of one hour, and extra food was given to them in their living-cages for about two hours. No other food was given until the following (non-experimental) day, when, as we have said, a full ration was

²The records of the conditioning of this group corroborate the results reported in (5).

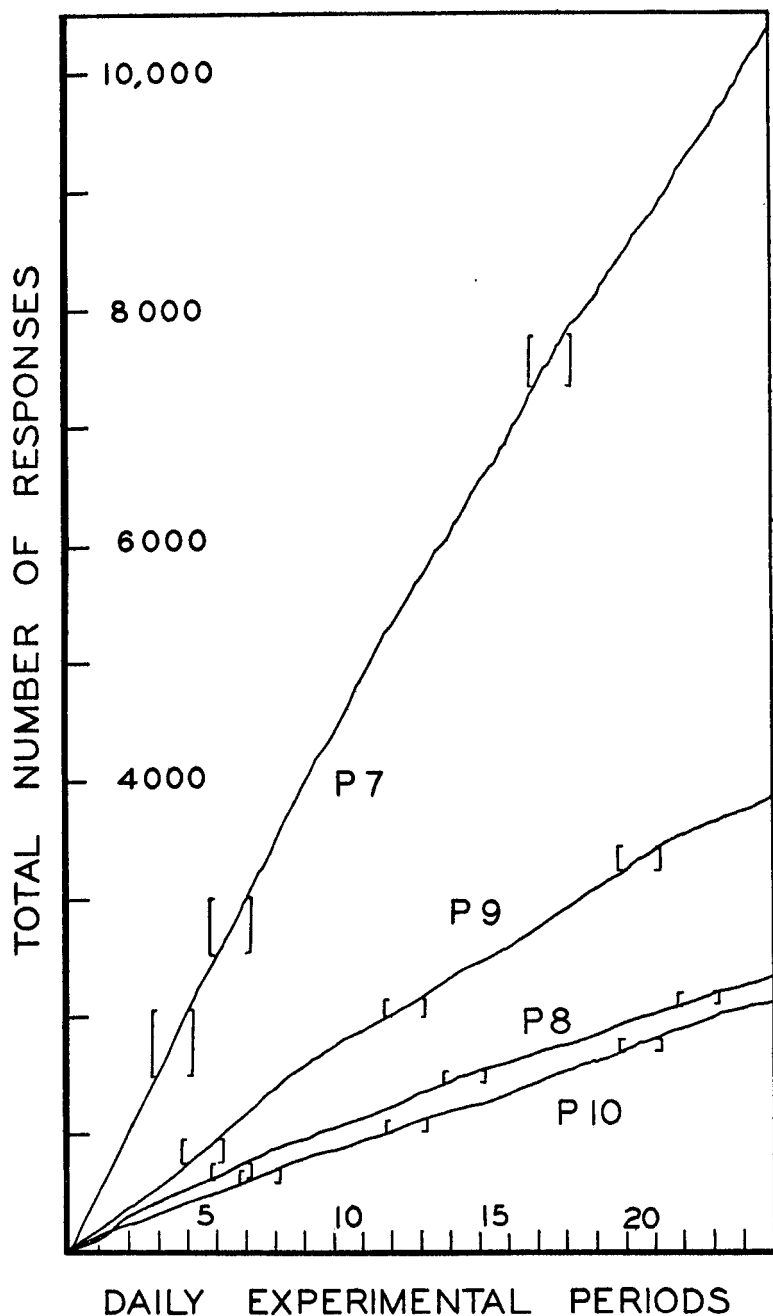


FIGURE 3
RESPONSES TO THE LEVER DURING 24 DAILY EXPERIMENTAL PERIODS OF ONE
HOUR EACH
Reconditioning as follows: P7 every three minutes, P9 every six minutes,
P8 every nine minutes, and P10 every twelve minutes

given at 9:00 A.M. This procedure was repeated for 24 experimental days.

The results are contained in four sets of 24 kymograph records, which describe the behavior of the rats with respect to the lever for a total of 96 experimental hours. The complete experiment is represented in Figure 3. The figure was constructed by plotting the total number of responses attained by the end of each day against the number of days. Between these separate points the approximate course of each daily record was drawn (free-hand). The details of the original records are lost in the unavoidable reduction in size. Typical records from each set, however, are reproduced in Figures 4 and 5, and their positions in Figure 3 are indicated with brackets in the latter figure, the order of occurrence corresponding in the two cases. Thus the curve for *P7* in Figure 3 represents a series of 24 kymograph records pieced together to form a continuous graph, of which Figure 4 shows, reading from left to right, the fourth, sixth, and seventeenth members.

The most obvious conclusion to be drawn from Figure 3 is that the value of the assumed rate is a function of the interval between successive reconditionings. The shorter the interval, the steeper the slope of the graph. We shall return shortly to this relationship. It is also apparent that no very significant change in rate is to be observed at any given interval during the period of the experiment. So far as each daily record is concerned, there is, in fact, no consistent deviation from a straight line, although all records show local irregularities.³ In the complete series, on the other hand, the rate of elicitation is not strictly constant, but shows a significant, though slight, decline. It is impossible at present to correlate so slight an effect with any specific condition of the experiment. The curves in Figure 3 cover a period of 47 days, a fairly large fraction of the active adult life of the organism, and there are many progressive changes to which an effect of this magnitude could be attributed. For any short section of the graph the curve may be regarded as essentially rectilinear.

V

Local deviations from a straight line peculiar to these records are of at least three clearly distinguishable orders. The first is unim-

³The curvature observed in some few instances (see *P9*, Figure 5) follows no consistent rule from day to day.

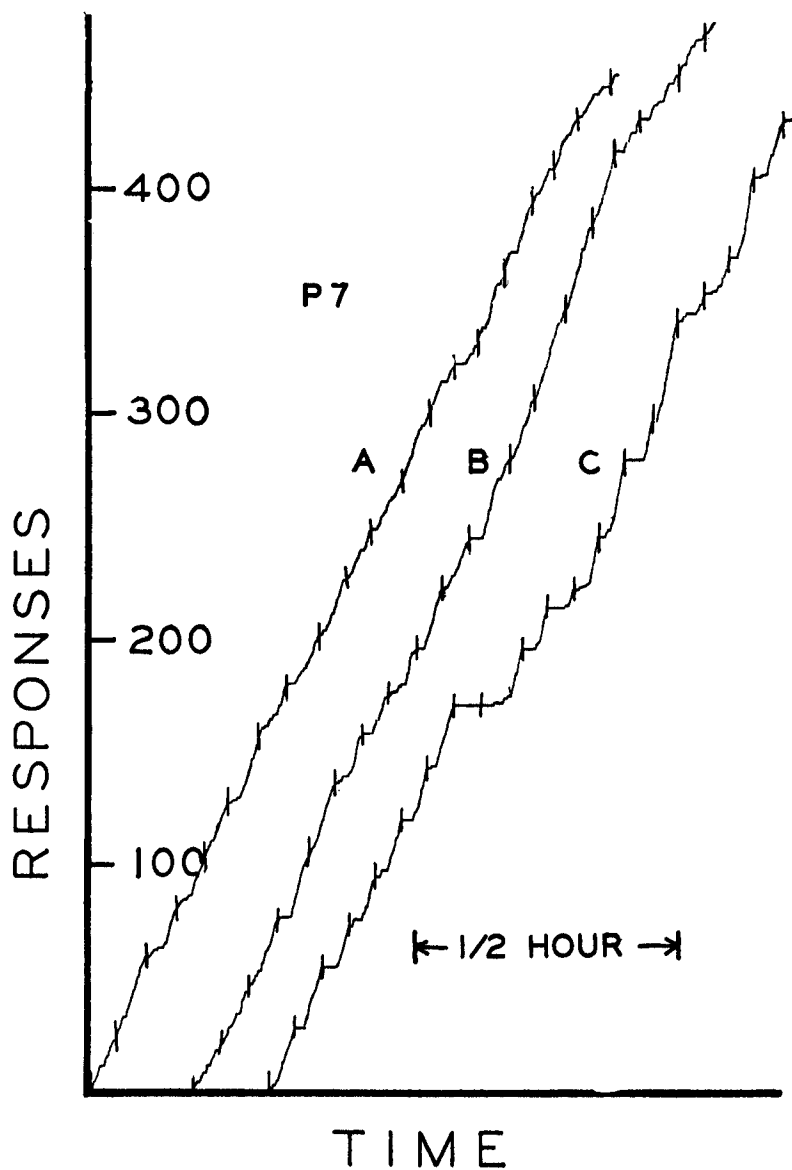


FIGURE 4

THREE DAILY RECORDS FROM THE SERIES FOR *P7* IN FIGURE 3
 The positions of these records are indicated in Figure 3 by brackets.

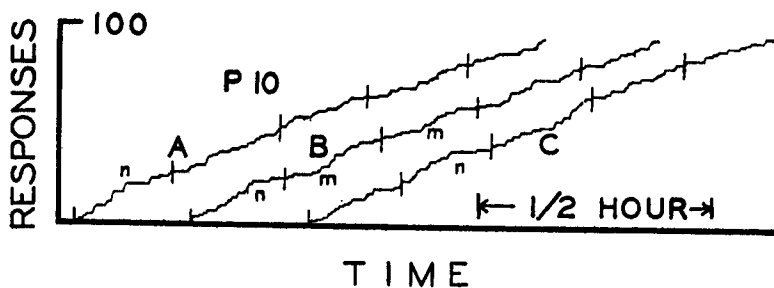
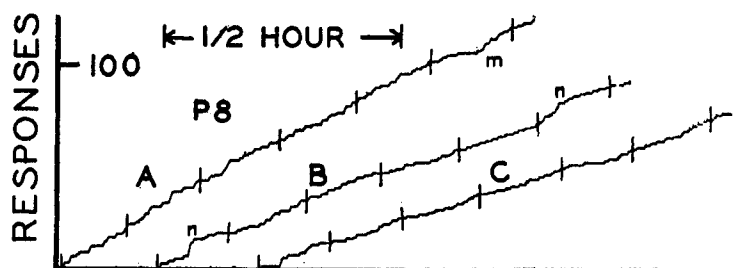
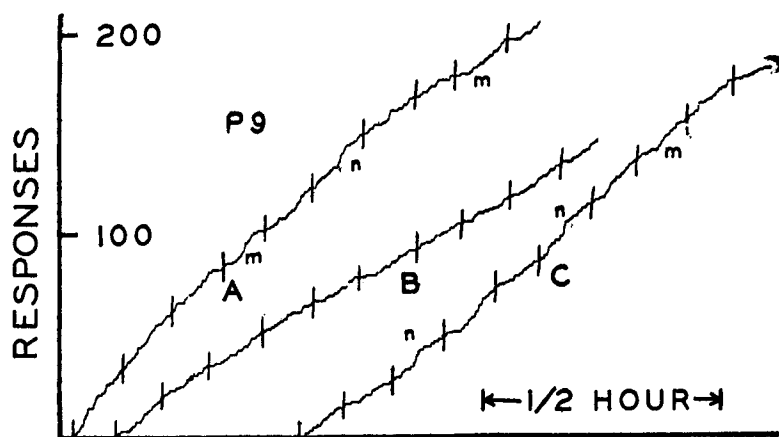


FIGURE 5

THREE DAILY RECORDS FROM THE SERIES FOR P9, P8, AND P10 IN FIGURE 3
The positions of these records are indicated in Figure 3 by brackets.

portant but may be described. If we ignore the curvature of the graphs in Figure 3, we must still take account of a variation of the following sort. The rate of elicitation first shows a slight but continuous increase, which may extend over a period of several days and which may be obscured by the progressive decline in rate that occurs simultaneously. Then, within a day (or at most two days) the rate falls to a value that is minimal for the curve in question. From this point there is a slow recovery, which may persist for several days. When the rate has again reached a relatively high value, another rapid drop occurs, and the recovery is subsequently repeated. The range over which the rate varies is small, but it is sufficient to give the records a slight "scalloped" effect. This characteristic is exceptionally prominent in the curve for *P9*, Figure 3, but it can be detected in the other curves by strongly fore-shortening them. Examples have also been found in other (unpublished) experiments. The cause of the variation is unknown.

Deviations of a second order are much more striking and are definitely correlated with the special conditions of the experiment. They are found only at the higher rates of elicitation (induced with more frequent reconditioning) and are not present during the first days of the experiment. There is no reliable sign of the effect in Figure 4 *A*, for the fourth day of the series, although deviations of this type have clearly appeared by the sixth day (record *B*). They resemble those of the first order, with the important exception that the duration is of an entirely different order of magnitude. In Figure 4 *B* it may be observed that the average rate of elicitation gradually increases until the sixth reinforcement. It is then suddenly depressed. There is a subsequent steady recovery, leading to a second maximum at the fourth reinforcement from the end. Here another depression appears, the recovery from which is interrupted by the termination of the period. The record is thus divided into three segments, each of positive acceleration, which meet at points showing definite discontinuity. The effect has become more clearly marked (although in this case somewhat more irregular) by the seventeenth day, record *C*.

A careful examination of these variations of the second order would take us too far afield, but we may note the following characteristics. First, the average basic rate of elicitation is unchanged. The three records in Figure 4, for example, are approximately parallel. We may therefore conclude that, secondly, the effect has

two discrete phases, one marked by an increase above the basic rate, and the other by a depression below it, which combine to give the basic rate as a resultant. The two phases may be observed in Figure 4 and in the figure about to be described (Figure 6). Thirdly, when a restriction is placed upon one phase, there is a corresponding adjustment of the other. Thus in Figure 4 the basic rate is already so high that any increase is probably faced with a practical limit.⁴ Accordingly, the depressed phase has no extensive compensation to make and is of fairly short duration. The two records in Figure 6, which may be compared with Figure 4, were obtained on successive days at the end of a long series of observations upon another rat (K12) where the interval of periodic reconditioning was five minutes. The basic rate (given approximately by a straight line drawn through the end points of each record) is relatively low. A very large increase is therefore possible and is actually observed—notably in the initial segments of the two curves. The periods of depressed rate are correspondingly more extensive. Figure 6 is thus a much better example of the second-order effect, since it demonstrates a fuller development of the augmented phase. It also shows clearly that the fundamental deviation is the increase in rate, and that the depressed phase enters only as a compensating factor.

The nature of variations of the second order is not wholly clear. Recalling our ideal series of all pairs of stimuli, we may regard the present procedure as one in which the two stimuli in a discrimination are identical. The conditions are therefore very similar to those in which there is an actual *but subliminal* difference between the stimuli. In the latter case a phenomenon of "breakdown" has been observed (*cf.* Pavlov, 1), which is characterized by sudden and usually violent changes in the strength of the reflex. The present effect may be one form (possibly only an incipient form) of breakdown. In any event the reality of the phenomenon can hardly be questioned. The instances shown in the accompanying records (and in very many others) cannot possibly be due to any chance distribution of various rates of elicitation.

Deviations of a third order appear as depressions in the rate of elicitation after the periodic reconditioning of the reflex. They are followed typically by compensatory increases, so that the total rate (as we have already seen) is unchanged. With a relatively short

⁴The apparatus, however, is capable of handling a rate at least 50 per cent above the highest here observed.

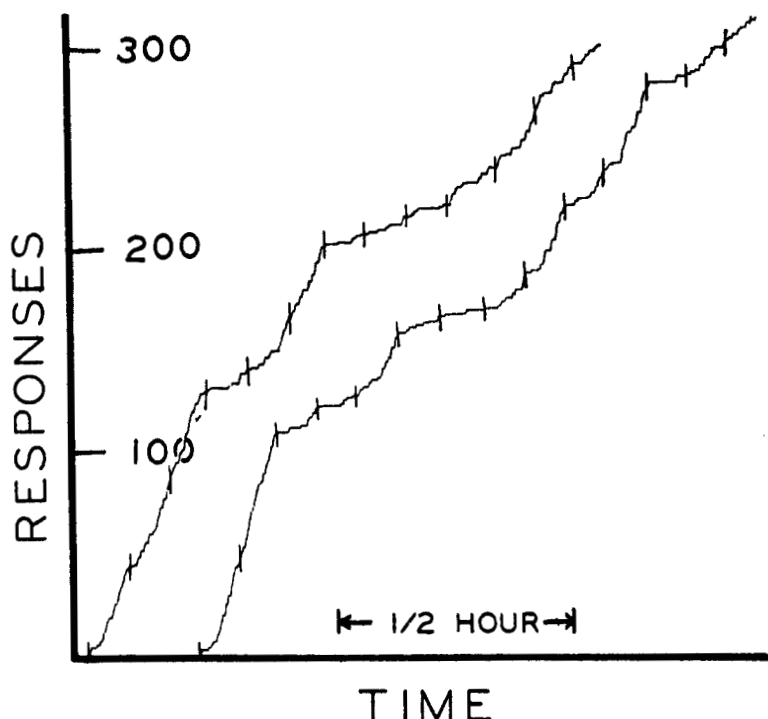


FIGURE 6

RECORDS FOR TWO SUCCESSIVE DAYS UNDER PERIODIC RECONDITIONING AT INTERVALS OF FIVE MINUTES, SHOWING UNUSUAL DEVELOPMENT OF DEVIATIONS OF THE SECOND ORDER

period of reconditioning the depressions begin to appear within a few days. They are already present to some extent in Figure 4, record *A*, and have become quite definite in record *B*. They give a step-like character to record *C*, on the seventeenth day of the series. The same effect is apparent, though to a lesser degree, in the records obtained with reconditioning at longer intervals (see Figure 5). Here their development is considerably retarded.

Such an effect would ordinarily be described as a conditioned inhibition. It is not clear, however, that the events fit any of the usual formulae for conditioning. The phenomenon may be regarded as reflex inhibition if we define the latter simply as a decrease in the

strength of a reflex correlated with the presentation of a second (extraneous) stimulus. Our observations, however, are limited to the following. Because of the character of the experimental procedure the relatively constant stimulation in the experimental box is supplemented periodically by a group of stimuli arising from the discharge of food from the magazine and from the ingestion of food by the rat. The periods of depressed rate that appear in our records are definitely correlated with the occurrence of this extraneous stimulation. Accordingly, by definition, the stimulation may be said to set up an "inhibitory effect." We may regard it, furthermore, as a *conditioned* inhibition, if that term has no more specific meaning than that the relation between the extraneous stimulus and the inhibitory effect is dependent upon the experimental history of the organism. In Appendix I we shall consider the possibility that these third-order deviations constitute a temporal discrimination, but for the present we shall not go beyond this simple description of the data.

We may note in addition, however, that there is a close relation between deviations of the second and third orders. Both appear on about the same day of the experiment and the beginning of the depressed phase of the second-order effect almost invariably coincides with a depression of the third order. Furthermore, since the extent of the deviations of the third order is in general a function of the rate, it varies with the rate during changes of the second order.

There are also deviations of a fourth order to be considered, but they are not peculiar to records obtained with this procedure. In the simplest case they are the result of the generally observed tendency of responses to occur in groups rather than in an equally spaced series—apparently an effect of threshold. In the more severe form of the deviation a period of no responding may become considerably extended—a matter either of threshold or of prepotency. A period of increased rate then follows, by virtue of which the rat "recovers" from the delay (3, 6). As a converse sort of deviation, which has so far been observed only in experiments involving extinction, the period of rapid responding may occur first, followed in turn by a compensating period of reduced rate (6). A few examples of the two effects have been indicated in Figure 5. Those marked *m* show an initial depression in rate followed by an increase; those marked *n* show the reverse. Many examples may be found in the other figures.

These four orders are clearly definable in terms of their observed

properties. Taken together, they account for all the deviations from a straight line found in the present records. The only possibility of confusion is between the third and fourth orders, which are of approximately the same magnitude: if a deviation of the fourth order should occur immediately after the reinforcement of a response, it would be indistinguishable from one of the third. For this reason it is difficult to detect the first appearance of the third-order effect, although the difficulty may be eliminated with a statistical treatment. In dealing with the process of discrimination we shall, as we have said, find it convenient to regard the graphs in Figure 3 and the daily curves composing them as essentially rectilinear. In this respect the deviations that we have examined raise no special problem. All four types show compensatory readjustments, and in no case is there a permanent deflection of the curve. Moreover, in the experiments upon discrimination we shall use a fairly moderate rate of elicitation, induced with a five-minute period of reconditioning, where deviations of the second and third orders are not present to any significant extent. The change observed during the establishment of a discrimination is also fortunately of such an order of magnitude that confusion with any one of these types is very unlikely.

VI

Having examined the extent to which our experimental curves are to be regarded as rectilinear, we may return to the relation between a given rate of elicitation and the period of reconditioning at which it is assumed by the rat. That the interval and the slope vary inversely is apparent in Figure 3, but the relationship is not wholly reliable because of the probable presence of individual differences. These may be allowed for either by using a large number of animals at each slope or by rotating a small number over a series of slopes. The former method has not been tried. An experiment with the latter yielded the following result.

Four intervals were chosen to cover the greater part of the change in slope in Figure 3, viz., 3, 5, 7, and 9 minutes. Four rats (*P3*, *P4*, *P5*, and *P6*), of the same strain and approximately the same age as in the previous experiment, were tested at all four intervals according to the schedule in Table 1.⁵ Each rat remained at each inter-

⁵This group had been conditioned 50 days before. Meanwhile, on alternate days, several aspects of the response had been studied. Most of the experiments required periodic reconditioning at 15-minute intervals for periods of 1 hour.

TABLE 1
INTERVALS OF RECONDITIONING

Day	P3	P4	P5	P6
(0)	(5)	(5)	(5)	(5)
1	3	5	7	9
2	3	5	7	9
3	5	7	9	3
4	5	7	9	3
5	7	9	3	5
6	7	9	3	5
7	9	3	5	7
8	9	3	5	7
9	3	5	7	9
10	3	5	7	9

TABLE 2
OBSERVED AVERAGE SLOPES

Interval	P3	P4	P5	P6	Mean slope
3 min.	53.2°	40.5°	62.9°	52.5°	52.3°
5 min.	47.5°	40.3°	59.0°	43.5°	47.6°
7 min.	44.0°	34.0°	54.8°	35.0°	41.9°
9 min.	36.0°	31.5°	44.5°	29.2°	35.3°
Average	45.2°	36.6°	55.3°	40.1°	

val two days and returned on its last two days to the interval at which it began. The slopes of the 40 records so obtained were measured with a protractor, using the beginning and end of each curve as the only significant points. The average slope for each rat at each interval is given in Table 2. Each entry is the average of two observations, except for the interval at which each rat began (see Table 1), where four observations were taken. That there are large individual differences is shown by the average slopes for the series regardless of length of interval, which range from 36.6° to 55.3°. The mean slope at each interval is free from the effect of this individual variation and is the result we desire.⁶

Before calculating the standard deviation of the mean, it is necessary to correct for individual differences. This has been done in

⁶The possible effect upon the means of the extra weight of the four-observation averages may for our present purposes be ignored.

the following way. A plot of the values in Table 2 justifies the tentative assumption that individual variation from the mean is absolute and may be expressed as a constant number of degrees, independent of the slope, within the range here observed. On this assumption the values for each rat were modified by adding or subtracting a characteristic number, which was chosen so that the sum of the squares of the deviations of the resulting values from the mean was a minimum (obtained graphically). The number chosen for each rat is given in the last line in Table 3. The corrected values, their means, the tangents, and the standard deviations of the means are also given in that table. The result is shown graphically in Figure 7, where the tangents of the means in Table 3 are plotted

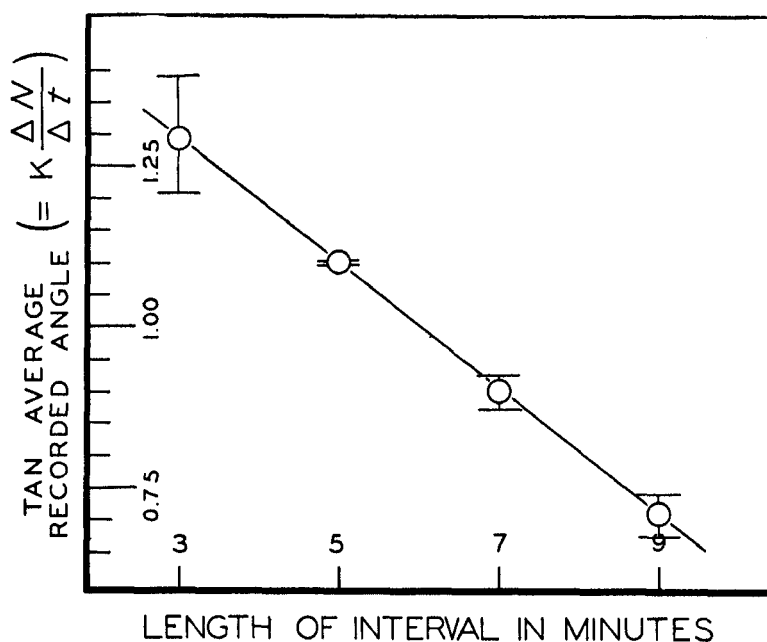


FIGURE 7

RELATION BETWEEN RATE OF ELICITATION (GIVEN BY THE TANGENT OF THE ANGLE MADE BY THE RECORD WITH THE HORIZONTAL) AND THE LENGTH OF THE INTERVAL OF RECONDITIONING

Horizontal bars mark off twice the standard deviations of the points.

TABLE 3
AVERAGE SLOPES CORRECTED FOR INDIVIDUAL DIFFERENCES

Interval	P3	P4	P5	P6	Mean slope	Tan mean slope	S.D. _m
3 min.	52.3°	48.2°	51.8°	57.0°	52.3°	1.29	±1.81°
5 min.	46.6°	48.0°	47.9°	48.0°	47.6°	1.10	±0.04°
7 min.	43.1°	41.7°	43.7°	39.5°	42.0°	0.90	±0.93°
9 min.	35.1°	39.2°	33.4°	33.7°	35.4°	0.71	±1.34°
Correction	-0.9°	+7.7°	-11.1°	+4.5°			

against the length of interval.⁷ The horizontal lines mark off twice the standard deviation of each point. A very good approximation to a straight line is apparent.

This relationship is doubtless to some extent fortuitous, since it is impossible in so short a series of observations to correct for the effect of "carry-over" from one experimental day to the next. If the rat has been responding to the lever at some constant rate, that rate will be assumed at the beginning of a new experimental period, even though the frequency of reconditioning in the new period is going to justify either a lower or a higher rate. Adjustment to the new frequency is quickly made, but the average for the full period necessarily shows the effect of the anomalous initial rate. Accordingly, since the intervals of 5, 7, and 9 minutes in the present schedule follow *shorter* intervals in each case, we should expect the values of the slopes observed upon the first days at these intervals to be to some extent too high. The three-minute intervals, on the other hand, follow longer intervals in every case, and the observed slopes are therefore probably too low. An actual carry-over is evident in most of the records as an initial positive or negative acceleration. This difficulty is inherent in the method and cannot be dealt with adequately until the extent and nature of the carry-over are better known. Some allowance could have been made by estimating the slope eventually attained at each interval, rather than respecting only the end points of each record, but this would have introduced an element of interpretation, which we have desired to avoid. The result given in Figure 7 is not intended to be independent of the particular

⁷We are interested in the tangent of the angle rather than in the angle itself, since the significant datum is the rate of elicitation.

conditions of the experiment. A relationship between slope and interval, free of the effect of any significant individual difference, is demonstrated, but its precise nature is not shown.

VII

In saying that the constant rate observed under periodic reconditioning is the result of the fusion of many separate extinction curves, we intend only to describe the behavior of the rat as reported, for example, in Figure 2. But even at this level the description is inaccurate, for a mere algebraic summation will not wholly account for the resulting curve. In every case so far examined the slope eventually assumed is less than the initial slope of the extinction curve, and it may be very much so where the frequency of reconditioning is relatively low (cf. Figure 5). In addition to the summation, therefore, we must recognize a factor operating to depress the rate immediately after reconditioning. Since it is originally not present, it may be supposed to be a "conditioned inhibition" similar to the deviations of the third order already described. It is possible that a single factor is involved in both cases, of which the third-order effect proper is only an extreme development. At the lower slopes the effect of the inhibition is to produce a surprisingly accurate leveling of the rate over an extensive series of experimental periods. Thus the records in Figure 5 give in general no reliable indication of the time at which reconditioning occurs. As the experiment progresses the local effect of each reconditioning is thus lost, and the only result to be observed at all is the continued maintenance of the steady rate. It is as if the repeated reconditioning had established a large reserve, which became the chief factor in determining the rate, and against which a single reinforcement could have little effect. We are still close, however, to a point at which the specific effect of the reconditioning may become apparent. Thus if alternate intervals of two and eight minutes are substituted for the usual five and five, the same total slope is maintained, but a local effect of the reconditioning is evident in the wave-like character of the record (Figure 8). The combined depressive effect of each pair is clearly shown.

VIII

The phenomena observed under periodic reconditioning obviously demand consideration in their own right. Only as much has been

given here as is necessary to an understanding of the experiments that follow. The principal fact with which we are concerned is that under an experimental procedure of alternate reconditioning and extinction a reflex assumes a constant strength, and that at a given frequency of reconditioning this strength is practically invariable. The relation of the procedure of periodic reconditioning to that of discrimination should be obvious. The former may be converted

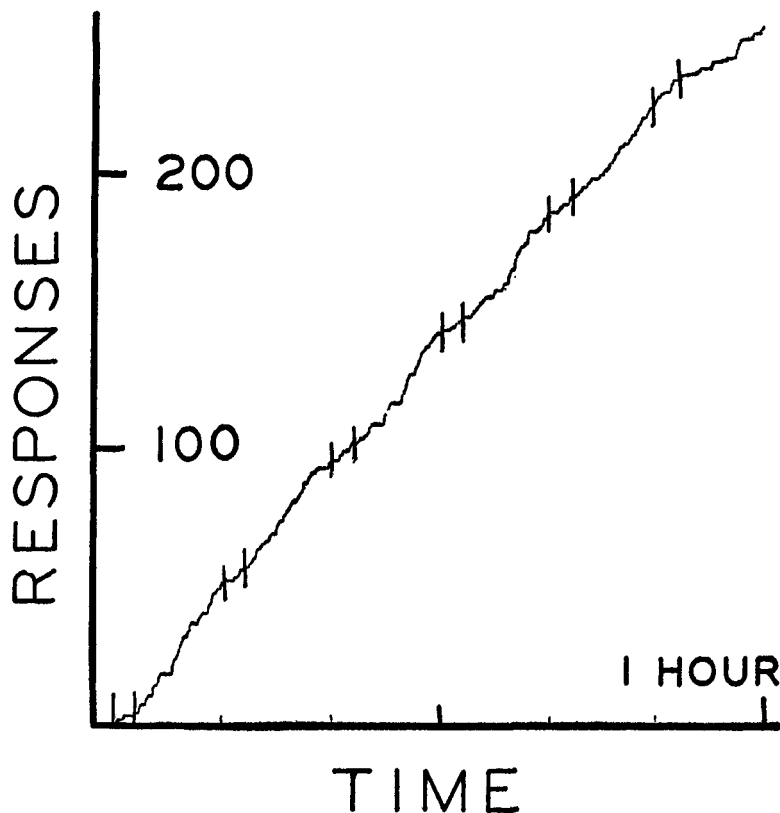


FIGURE 8

WAVE-LIKE RECORD OBTAINED BY GROUPING SUCCESSIVE RECONDITIONINGS,
GIVING INTERVALS OF TWO AND EIGHT RATHER THAN FIVE
AND FIVE MINUTES

The local depressive effect of the reconditioning is additive.

into the latter simply by introducing extra stimulating material whenever the response is either reinforced or extinguished. There are then two stimuli that elicit the response (both of which are, strictly speaking, *groups* of stimuli), which differ only with respect to the added member. We shall consider here only the case in which the addition is made in such a way that the response to the group containing the added material is reinforced and the response to the group lacking it is not. It will be readily understood that the change to appear experimentally during the development of the discrimination is a progressive lowering of the slope of the graph established under the procedure of periodic reconditioning.

Four male rats of the same strain, *P11*, *P12*, *P13*, *P14*, were conditioned to respond to the lever at the age of 100 days. Three days later they were transferred directly to periodic reconditioning, without any intervening extinction,⁸ at an interval of five minutes. This interval had given the lowest standard deviation in the experiment in Figure 7. It also yields (with this strain of rats) a rate moderate enough to permit significant changes in both directions and practically free of deviations of the second and third orders. The experiments were conducted for periods of one hour on alternate days, and the other details of the procedure outlined above were followed. Three daily records of periodic reconditioning were obtained, during which characteristic constant slopes were well stabilized. The procedure was then changed to include either the light or the sound (sound with *P11* and *P12*, light with *P13* and *P14*).

The discriminative procedure for a single day was as follows. As the animal was released, both the light and the magazine had been connected, and the first response to the lever, in the presence of the light, was reinforced with a pellet of food. Both light and magazine were then turned off, and the responses during the next five minutes were unreinforced. At the end of that time the light and magazine were turned on, care being taken that this was not synchronous with a response. When a response had been made (and reinforced), the light and magazine were again turned off, and this was repeated for a total of twelve reinforcements. At the end of the last interval no response was reinforced, and the animal was removed from the

⁸Differing in this respect from *P7*, *P8*, *P9*, and *P10*. The curves for the first day show an algebraic summation of the typical extinction curve with the curve of positive acceleration obtained at the beginning of periodic reconditioning after previous extinction (Figure 2).

box. The sound was used in the same way, with the exception already noted. The procedure was repeated for ten days.

The delay in obtaining the pellet was not added to the interval. This not only simplifies the treatment of the data but is a necessary part of the procedure in a discrimination, since the first significant change in the behavior of the rat is the shortening of the delay. The response to the lever-plus-light (or sound) immediately increases in strength from the resultant value given by the constant slope to

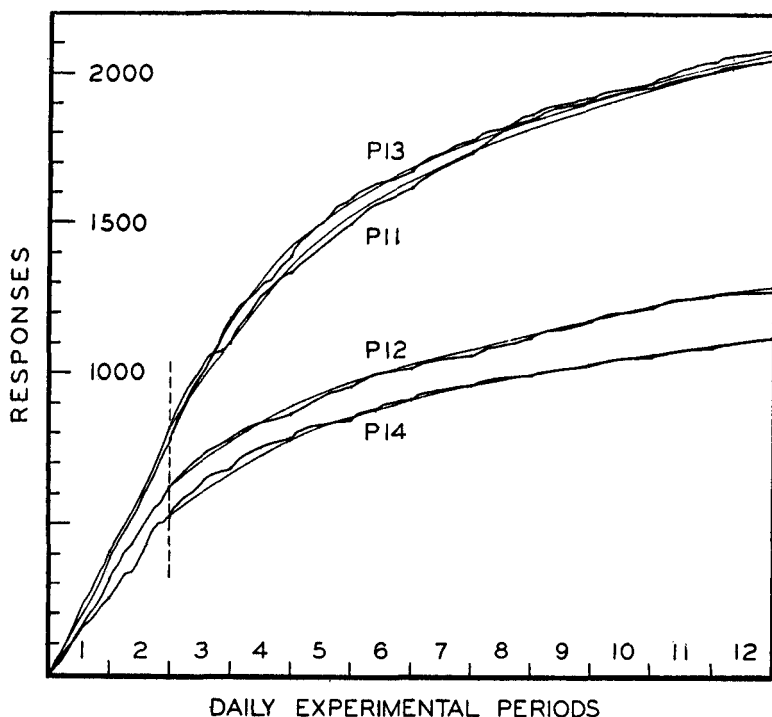


FIGURE 9

CHANGE IN THE SLOPE ASSUMED UNDER PERIODIC RECONDITIONING AFTER THE INTRODUCTION (AT THE VERTICAL BROKEN LINE) OF A DIFFERENTIATING STIMULUS AT EACH RECONDITIONING

Heavier lines are experimental. Lighter lines are for the equation $N = K \log t + C + ct$ where N = number of responses at time t and K , C , and c are constants having the magnitudes given in the text.

an approximately maximal value. As we have noted, we are not concerned with this change in the strength of the reinforced reflex,⁹ but the change in the length of the delay must not be allowed to affect the interval. Otherwise the correlated change in the total slope would appear as an artifact.

The result of the experiment is given in Figure 9, where the records for each rat for two days prior to and for ten days following the change in technique have been pieced together to form continuous graphs (the heavier lines in the figure). Since the detail is again lost in the reduction, the first eight records after the beginning of the discrimination have been reproduced from two typical sets, in Figures 10 and 11. Figure 10 is for a rat showing a relatively high basic rate under periodic reconditioning; Figure 11, for one showing a lower rate. In Figure 10 a sound was used in establishing the discrimination; in Figure 11, a light. There is no correlation between a greater slope and the use of a sound.

The first two days in Figure 9 are given as controls. They establish the slopes assumed under periodic reconditioning immediately prior to the discrimination.¹⁰ In view of the result given in Figure 3, we may assume that no significant change in these slopes will be observed so long as the experimental procedure is unmodified. It is evident, however, that, as soon as the technique is converted into that of discrimination by the introduction of a differentiating stimulus, the slope of each curve begins to fall off. The strength of the reflex in response to lever-plus-light remains maximal, but the reflex in response to the lever alone gradually decreases in strength, and a very low value is eventually reached.

The change is not rapid enough to be very clearly revealed at the end of a single hour. Nevertheless, the records for the first day evidently depart from the usual straight line and assume a characteristic curvature, convex upward, which is also assumed on succeeding days. The course may be at times severely distorted by deviations of the fourth order. In particular there is a tendency toward overshooting—a period of very active responding followed by a compensatory decrease in the rate of elicitation. Seven ex-

⁹The rate of the change may be estimated from the fact that an average basic value for the delay varying between two and ten seconds is reached after about ten reinforcements.

¹⁰Some individual variation is apparent, as we should expect from the experiment described in Section VI.

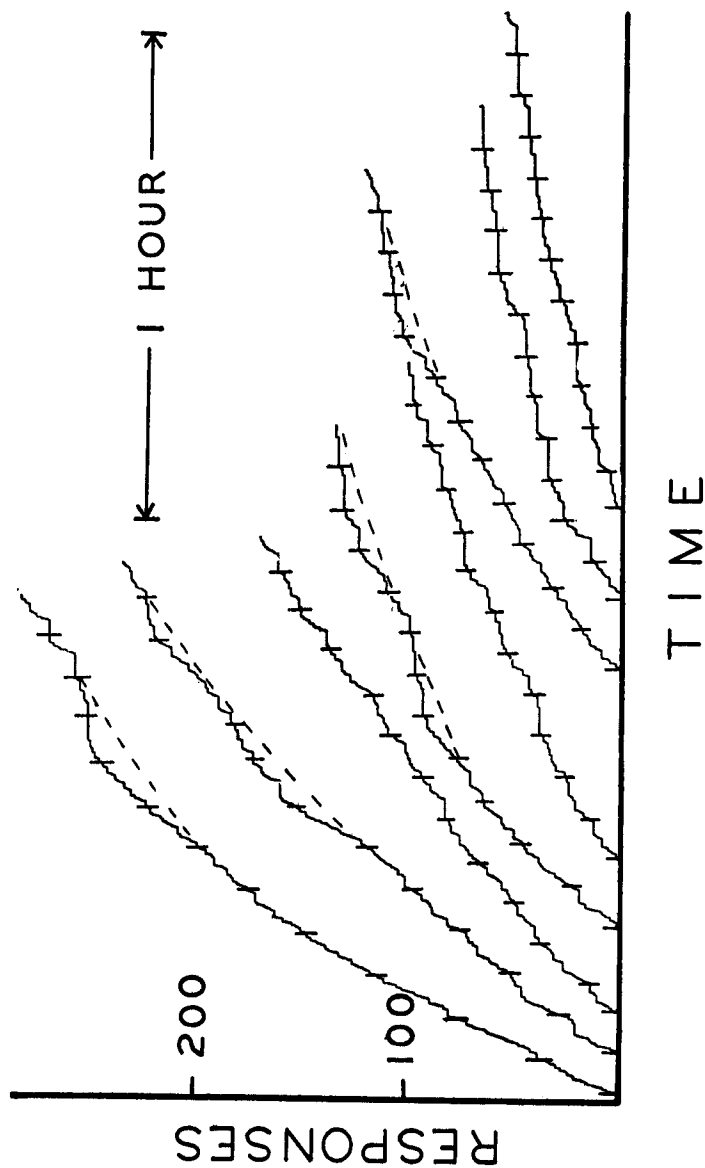


FIGURE 10

FIRST EIGHT DAILY RECORDS FOR P11 IN THE SERIES BEGINNING AT THE VERTICAL BOLD LINE IN FIGURE 9

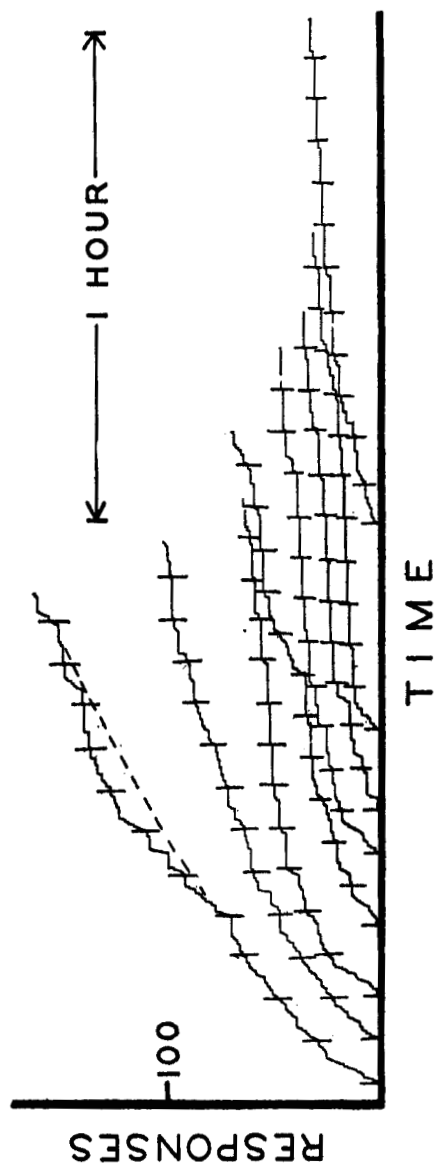


FIGURE 11
FIRST EIGHT RECORDS FOR P14 IN THE SERIES BEGINNING AT THE VERTICAL
BROKEN LINE IN FIGURE 9

amples of the latter effect have been indicated in Figures 10 and 11, where the probable course of each curve in the absence of the effect has been traced with broken lines. Other deviations are less extensive, and in general the course of each record may be easily inferred. With an occasional exception the daily slope progressively declines during the ten days of the experiment.

No attempt will be made to describe the change taking place during a single hour. It is comparatively slight, and the records are subject to too many incidental variations to make a quantitative description either convincing or useful for our present purposes. The greater change during the full course of the discrimination is, however, more significant. We may deal with this by respecting only the end points of each daily record. It is not difficult to describe these with an empirical equation. In Figure 9 theoretical curves (the lighter lines) have been drawn through the experimental data. They are for the equation

$$N = K \log t + C + ct$$

where N = number of responses to the lever and t is time in hours from the beginning of the use of the discriminative technique. K , C , and c are constants having the following values:

	P11	P12	P13	P14	Av.
K	825	295	765	375	565
C	265	130	370	105	218
c	15	25	15	10	16

We are interested, to be exact, in the first derivative of this equation, since our fundamental datum is the change in rate. For obvious reasons we are forced to record the integral form of the curve, and in order to remain as close as possible to our observations this form is reproduced here. Little would be gained in publishing at the same time corresponding figures obtained through graphical differentiation. To avoid confusion, therefore, we shall leave the equation also in the integral form. It should be noted that the coordinates in Figure 9 do not begin at zero so far as the process of discrimination is concerned.

The validity of this description is restricted by the following considerations. First, we may repeat that the fit is to the end points of the daily records only. We could not expect to fit the body of each curve with so simple an equation. The time represented by t is not continuous, but a succession of discrete periods, and

the curve for discrimination, interrupted at the close of one hour, does not continue unchanged at the resumption of the experiment 47 hours later.¹¹ Lacking a quantitative treatment of the daily change, we must resort to some such treatment as the present, where the records are pieced together to form continuous graphs. We are thereby, of course, simply taking the height of the daily curve at an arbitrary point as a convenient measure of the behavior for the day.

The practice introduces a probable source of error: when a given daily experiment is brought to its close, the curve may be at the moment in the course of a deviation. As in the experiment described above in Section VI, we could allow for this by estimating from the body of the curve the most probable end point. We wish, however, to introduce no such element of interpretation into the present report. And in accepting the end point as recorded we are possibly justified by the probability of a compensating adjustment on the following day. The most serious deviations in the present case are those of "overshooting." As a result, the end points of the records for the first days (where the overshooting is most prominent) lie, if not upon, above the theoretical curves.

Another possibility of error arises because the daily rate certainly depends in some way upon the hunger of the rat, although this point has not been checked experimentally for exactly these conditions. In the present study we were not prepared to include hunger as an independent variable, and it was therefore necessary to maintain it as constant as possible. The results obtained with periodic reconditioning (Figure 3) are an adequate check against any significant variation from day to day. Nevertheless, even with the most careful feeding, occasional temporary disturbances in the condition of an animal are certain to appear. The sixth record for *P11* in Figure 10, for example, is obviously much too high, and it is reasonable to attribute the abnormality to a condition of increased hunger. It is not clear whether the extra responses in the record are borrowed from later records in the series, or whether the total curve is displaced bodily from the anomalous day onward. The curve for *P11* in Figure 9 has been fitted, however, as if the increase on the sixth day were compensated for during the two days immediately following. In this case the treatment seems to be justified by the records, but

¹¹The increase in the strength of the reflex during an interval of this sort has been noted elsewhere [cf. the discussion of "loss of extinction" in (6)].

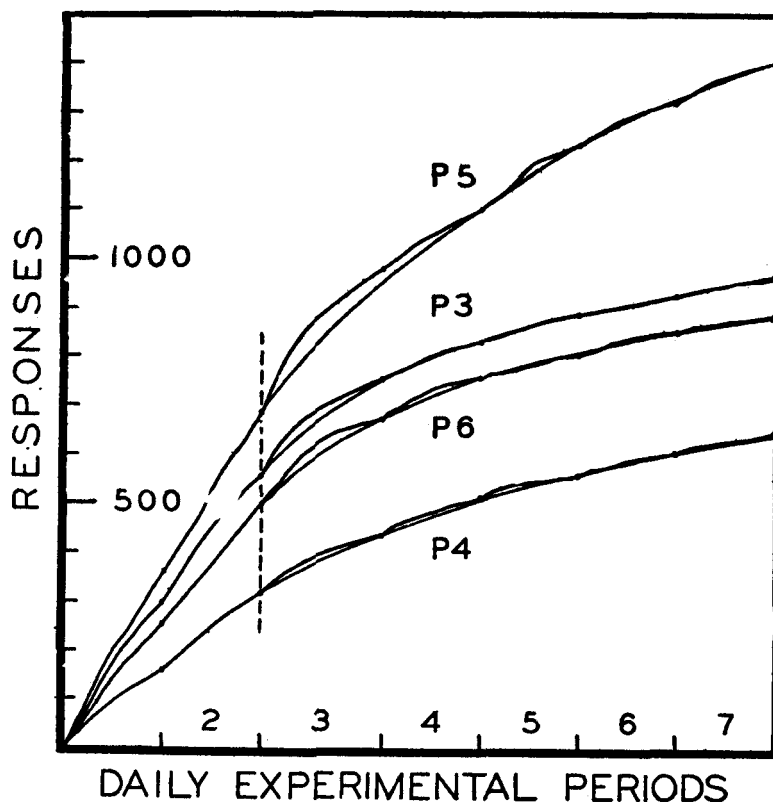


FIGURE 12

CHANGE IN THE SLOPE ASSUMED UNDER PERIODIC RECONDITIONING WHEN THE RECONDITIONING IS DISCONTINUED (AT THE VERTICAL BROKEN LINE)

Heavier lines are experimental. Lighter lines are for the same equation as in Figure 9.

the general interpretation of the effect of hunger obviously requires further experimental work.¹²

Within these limits, the curves we have obtained represent the development of a discrimination, and the process may therefore be described tentatively with an equation that is logarithmic and contains three constants. We have elsewhere reported that the curve

¹²The term "hunger" is used here in accordance with a previous discussion (3).

typically obtained for the original extinction of such a reflex is also logarithmic (6). This is significant. It indicates that the two processes are, as we have said, related; and that in a discrimination we are in fact dealing with the continued reinforcement of one reflex (which does not affect the slope observed under periodic reconditioning) and the concurrent extinction of another (which produces a progressive decline). However, we have not examined extinction under the present circumstances, that is to say, after prolonged periodic reconditioning. We must turn to this question before extending our comparison.

IX

The properties of extinction following prolonged periodic reconditioning have been studied with the group of four rats used in the experiment represented in Figure 7 (*P3*, *P4*, *P5*, and *P6*). Following the rotation of four intervals as described the rats were given three days with alternate intervals of two and eight minutes (records of the type shown in Figure 9 were obtained) and two days with intervals of five minutes. The response to the lever was then extinguished for five days. The rats were placed in their respective boxes on these days in the usual way, but the periodic reconditioning was omitted, and none of the responses to the lever was reinforced.

The results are given in Figure 12, which was constructed in the same way as Figures 3 and 9. The first two days give the control slopes under periodic reconditioning at an interval of five minutes.¹³ The individual variation follows the order already given for these rats in the fifth line in Table 2, that is, $P5 > P3 > P6 > P4$. The extinction extends from the third to the seventh day. The first four records during extinction are reproduced from two typical sets (*P3* and *P4*), in Figures 13 and 14 respectively. By comparing Figure 12 with Figure 9 (and noting the difference in scale) it will be seen that we are here concerned with a more rapid change. Although the records for the first day of discrimination showed some curvature, it was slight. In extinction, on the other hand, there is an extensive change within a single day.¹⁴ Subsequently the two

¹³The record for the second day for *P6* was destroyed through a difficulty with the apparatus. The slope given in Figure 12 was estimated from the previous performance of the rat.

¹⁴In order to show the character of the change more clearly the first period has been extended to $1\frac{1}{4}$ hours. In fitting the curves for the series

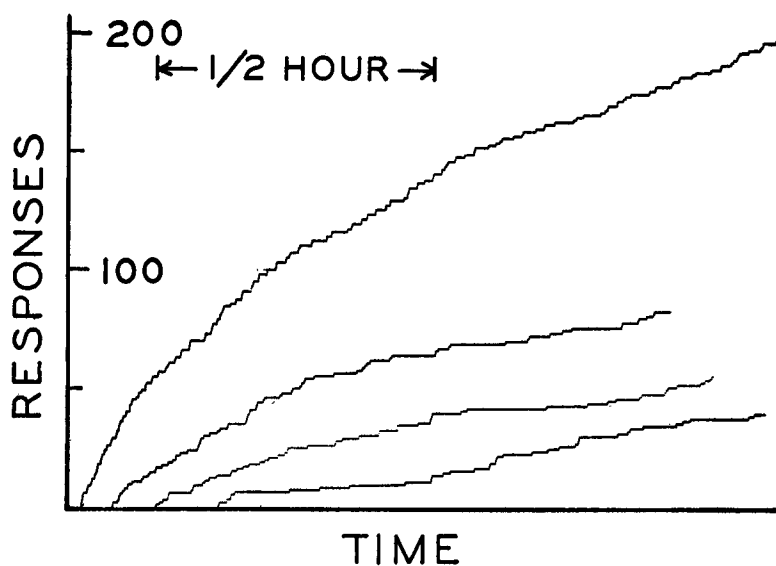


FIGURE 13

FIRST FOUR DAILY RECORDS FOR *P3* FROM THE SERIES BEGINNING AT THE VERTICAL BROKEN LINE IN FIGURE 12

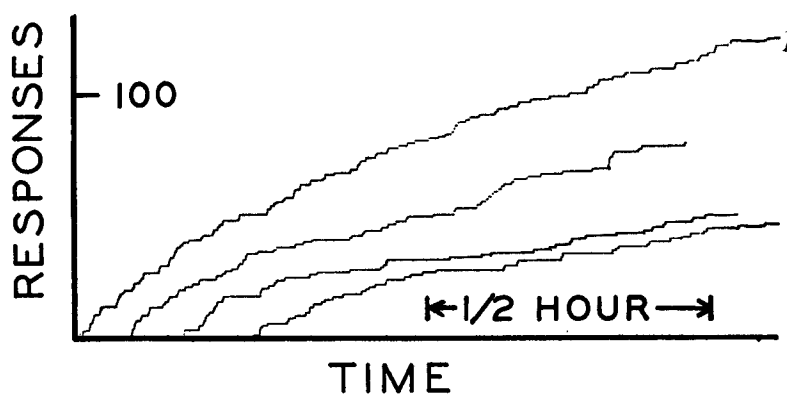


FIGURE 14

FIRST FOUR DAILY RECORDS FOR *P4* FROM THE SERIES BEGINNING AT THE VERTICAL BROKEN LINE IN FIGURE 12

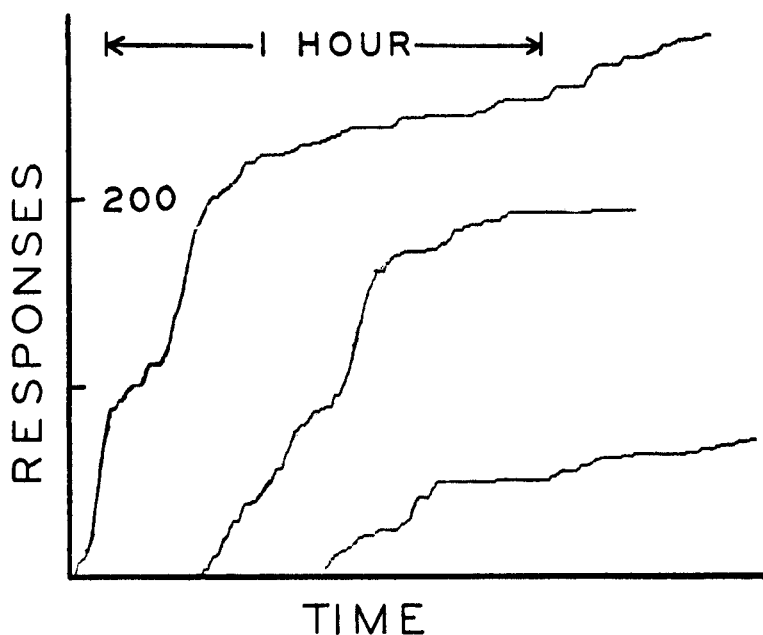


FIGURE 15

FIRST THREE DAYS OF EXTINCTION FOR *P7* AFTER THE PROLONGED PERIODIC RECONDITIONING SHOWN IN FIGURE 3

Note the extensive "overshooting" in the first two records with a trace in the third.

processes differ less sharply, although the decline in the total slope from day to day is much swifter during extinction. A characteristic curvature is maintained in the records. When the rate has become very low, the influence of incidental factors may be strongly felt.

Except for the difference in curvature, the records for the two processes are obviously similar. This is also true for the quantitative description. The theoretical curves in Figure 12 (lighter lines) are for the equation already given, but where the constants have the following values:

the first period is regarded as $1\frac{1}{4}$ days, and the other points are taken as $2\frac{1}{4}$, $3\frac{1}{4}$ days, and so on. This procedure is based upon the assumption that the important variable is time-in-the-experimental-box. The assumption may need modification when the nature of the daily record (including the question of "loss of extinction") is better known, but it is sufficient for our present degree of approximation.

	<i>P</i> 3	<i>P</i> 4	<i>P</i> 5	<i>P</i> 6	Av.
<i>K</i>	215	240	560	335	338
<i>C</i>	155	70	180	145	138
<i>c</i>	20	15	25	0	15

The validity of this description is likewise dependent upon the considerations noted above.

As in the case of discrimination, there are frequent examples of overshooting. As we shall see in Appendix II, the departure of the first day from the theoretical curve must be taken as an example. These departures depend in part upon the basic rate assumed under periodic reconditioning, but they are also related to the length of time during which the rat has been subject to the procedure of reconditioning. In Figure 15 the first three days of the extinction of the reflex in rat *P*7 are represented. The process was begun after the prolonged periodic reconditioning shown in Figure 3. It will be seen that during the first 20 minutes indicated in the first record the rat pressed the lever more than two hundred times. That this was, however, a temporary "strained" state is shown in the period of compensation that followed, during which the rat responded only desultorily for a period of more than an hour, and at the end of which the curve was probably close to its theoretical position (it is obviously difficult to infer the "true" course of the record). The transition from the high rate to the depression that follows is remarkably smooth. A similar overshooting occurs on the second day, and there is a trace of it on the third. Although these examples are extreme, they demonstrate the properties of the effect more adequately than the instances shown above, where the transitional stage is brief and usually obscured.

We should not expect the daily records obtained with this procedure to have the properties of the curve for original extinction (6), for we cannot legitimately assume that the intervening period of reconditioning has been without effect. In the present series the greater part of the curvature for the first day is, in fact, not due to extinction but to overshooting (see Appendix II). We have to show, however, simply that the curves given by the end points of successive daily records are similar in the two cases; and, on the assumption that compensation for overshooting or for any similar effect is complete, we may disregard the character of the daily curve altogether.

Since the curves in Figures 9 and 12 are fitted reasonably well

with a single equation, it should be possible, with the use of suitably chosen additive and multiplicative factors, to superpose them. If they are transferred to semi-logarithmic coordinates, the fit of the equation can be tested at the same time by superposing both sets upon a single straight line. This has been done in Figure 16, where the constants C and c have been reduced to zero, and K has been converted to 500 as a convenient and typical slope. The points represent the averages of the four sets of values in each experimental group. The open circles are the data for discrimination (Figure 9); the half-shaded circles are for extinction (Figure 12). Note that the latter occur at $1\frac{1}{4}$, $2\frac{1}{4}$. . . hours, as explained in footnote 14. The horizontal lines through each point mark off twice the standard deviation.

X

To the extent that the points in Figure 16 fall on the same straight line, the equation is a satisfactory description of both processes. But

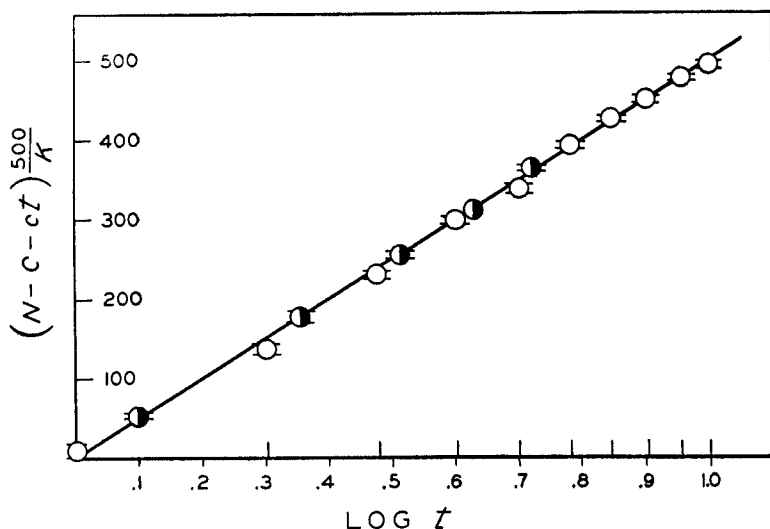


FIGURE 16

END POINTS FROM THE DAILY RECORDS IN FIGURES 9 AND 12, MODIFIED BY THE ADDITION AND MULTIPLICATION OF SUITABLE FACTORS AND SUPERPOSED UPON A SINGLE STRAIGHT LINE UPON LOGARITHMIC COORDINATES

The horizontal bars mark off twice the standard deviation of the points.

it should be emphasized that it is an empirical description only. No theoretical significance is attached to any of the constants. There are, in fact, several difficulties inherent in the equation as it stands. For example, it does not express the character of the curve as a departure from a basic rate, which is also a limiting rate. But, while it will need ultimate revision, the equation is at present adequate. In the system with which we are dealing there are other parameters of which account must be taken, and until they have been at least superficially examined any attempt at a theoretical interpretation may be suppressed.

The empirical equation is useful since, in view of the reasonably good fit demonstrated in Figure 16, it is possible to express differences between the two processes simply in terms of the values of the three constants. As we have already noted, we are ultimately interested in the first derivative, where C will have disappeared. Of the other two constants c takes a small value experimentally and does not differ appreciably between groups. This leaves K as the only notable difference. The average values of K are 565 for discrimination and 338 for extinction—a significant difference, although there is considerable individual variation, with some overlap. Part of the difference may be explained in the following way. It may be seen from an inspection of the figures that the value of K is related to the basic slope assumed under periodic reconditioning; for example, the curves showing greater slopes for days 1 and 2 in Figures 9 and 12 also have greater slopes during the subsequent change. The average slopes for the first two days in Figures 9 and 12 are 59° and 51° respectively, and we should therefore expect a lower slope in the latter case after the change has begun. But these values will not account for the whole difference in the values of K obtained above, and we must therefore conclude that K is characteristically higher during discrimination than during extinction.

Let us return to the notion of an ideal series of all pairs of stimuli. We now have records of discrimination at three representative points in such a series. First, as we have already said, the simple procedure of periodic reconditioning may be regarded as identical with that of a discrimination in which there is only a subliminal difference between the stimuli. Secondly, the curve for extinction (as given herein) will obtain where the two stimuli differ so completely that

their mutual interference is negligible.¹⁵ And, thirdly, we have a pair of stimuli, composed of the lever alone and the lever-plus-light-or-sound, which lies midway along the series. The records obtained in the first and second cases describe, respectively, the upper and lower limits for curves of this sort. The third gives a probably typical intermediate position.

It is significant that the two limiting curves are obtained with pairs of stimuli taken from the ends of our series. To this extent there is a demonstrable correspondence between the position of a given experimental curve among other curves and the position of its appropriate pair of stimuli among other pairs of stimuli, and it is a reasonable assumption (which, indeed, we have already implied) that the correspondence holds throughout.¹⁶ While our empirical equation is not theoretically adequate near the upper limit of the experiment range, we may still express the position of the curve for discrimination obtained in the present case by giving its value of K . Assuming this or a similar practice to be valid, what we may hope to obtain eventually is an ordering of pairs of stimuli according to the values of K that they yield.¹⁷ This result would immediately afford an answer to most of the questions in connection with which the method of discrimination is now employed.

Aside from the use of K in determining what constitutes a significant difference in a property of a stimulus, the present result has an important bearing upon the nature of the problem of discrimination itself. Primarily it confirms our hypothesis that the process of discrimination is only a special case of extinction. But it also enables us to define the problem a little more closely. We have seen that in a discrimination if it were not for the periodic reinforcement of a related reflex the strength of the unreinforced reflex would decrease

¹⁵This might be the case, for example, if, instead of the simple addition of a light, the location of the lever, its shape, direction of movement, and so on could all be changed whenever the response was reinforced—in other words, if there could be two quite different levers, alternately available, the response to one of which was reinforced, the response to the other not.

¹⁶If we examine the procedure with which we arrange pairs of stimuli "according to the degree to which they possess their properties in common," we may find that our definition of a significant or differentiating property rests ultimately upon the rôle of the property in establishing a discrimination (if not by the organism at least by the experimenter). The correspondence that we have noted would then become virtually an identity.

¹⁷Any number of pairs of stimuli may, of course, occupy a single position in the series (if they possess the same value of K).

according to the first derivative of the curve for extinction. The *observed effect* of the reinforcement is the presence in the curve (for discrimination) of a number of extra responses per interval. These additional responses may be said to be due to the reinforcement of the related reflex in the sense explained in Appendix II. But (as we imply in saying that the modification takes the form of an increase in K) the number of these additional responses per interval (and therefore per reinforcement) does not remain constant during the process. The extent of the interference, to be exact, varies as the strength of the reflex undergoing extinction. Since the problem of discrimination arises because of the mutual influence of two related processes, it should be especially concerned with the nature of their interference. We may now regard the interference as in itself a process, and we may deduce some of its properties from the above discussion.

XI

Some explanation of the present method may now be required. In general, its characteristics have been determined by the subject-matter. As we have seen, a discrimination inevitably requires the alternate reconditioning and extinction of two related reflexes, so that some form of periodic reconditioning is a part of any available procedure. The *regularity* of the period in the present case is determined by the further consideration that we wish to use a rate of elicitation as a measure of reflex strength. Thus, while the use of "periodic reconditioning" may at first seem to be artificial or unnecessary, it is actually only an attempt to deal as directly as possible with a basic condition of this type of experiment. The objection that the regularity may introduce an artifact through "temporal conditioning" is met by the control curves in Figure 7 and by the theoretical remarks in Appendix I. Fortunately the baseline provided by periodic reconditioning is rectilinear, but the method would have been equally valid if it had proved otherwise.

The complexities of the account are likewise chiefly due to the subject-matter, and if they do not appear in an investigation with another method it is probably the fault of the method. Difficulties in fitting and interpreting curves cannot arise until reproducible curves have been obtained. Likewise, if the several orders of deviations peculiar to a discrimination appear here for the first time, they are none the less real phenomena; and any investigation in which they do not appear may be only deceptively simple.

One aspect of the present method may deserve comment, namely, its freedom from personal interpretation. Ordinarily the presence of the experimenter is not required during the experimental hour. Where periodic administrations of food are required, an exception must, of course, be made. But even then it may still be said that between the actual behavior of the rat and all the figures in the present paper there intervene only mechanical or mathematical steps.

SUMMARY

(I) Technically the establishment of a discrimination consists of the continued reinforcement of one reflex and the concurrent extinction of another, where the two stimuli possess properties in common but also differ in some significant respect. The two processes cannot go on independently, and the problem of discrimination arises because of their mutual interference. The present paper examines the nature of this interference and tests the expected similarity of properties of the two processes.

(II) The apparatus consists of a suitably controlled experimental box in which there is a small lever, which may be pressed downward by a rat. The movement of the lever may or may not be followed by the delivery of a pellet of food to the rat, according to the wish of the experimenter. The box also contains an extra source of stimulating energy under the control of the experimenter, either a light or a sound, to be used as a differentiating stimulus in establishing a discrimination.

(III) If the response to the lever is periodically reinforced with a pellet of food (say at an interval of five minutes), while all intervening responses are extinguished, the successive separate extinction curves recorded with a method previously described eventually fuse, and a constant rate of elicitation is assumed. (IV) This rate may be maintained for as long as 24 experimental hours. (V) There are three orders of local deviations from such a straight line peculiar to the records and a fourth order common to all records obtained with the method. The four orders are described. (VI) The constant rate of elicitation is a function of the frequency of reconditioning. (VII) The constant rate is due not only to the summation of separate extinction curves but to a factor which depresses the rate immediately after a reconditioning. The depressive effect can be demonstrated by a modification in technique.

(VIII) The procedure of periodic reconditioning may be con-

verted into one of discrimination by adding extra stimulating material whenever the response is to be reinforced. As soon as this is done the rate assumed under periodic reconditioning begins to decline and the resulting records describe curves that are fitted with the equation

$$N = K \log t + C + ct$$

where N = number of responses, t = time in hours from the change in technique, and K , C , and c are constants. (IX) Curves obtained for pure extinction after prolonged periodic reconditioning are also described with the same equation. The two sets of data are tested by adjusting the values of the constants and superposing both sets upon the same straight line on semi-logarithmic coordinates.

(X) Although the equation is purely empirical and no significance is attached to the constants, the effect upon the curve for extinction of the concurrent reinforcement of a related reflex can be expressed as an increase in the value of the constant K . The upper and lower limits between which a curve for discrimination may lie are described. In the lower part of the range the position of a curve is expressed by K . The position is probably determined by the degree to which the properties of the two stimuli in the discrimination possess their properties in common. K may thus be used in determining what constitutes a significant property.

The extent of the effect of the reconditioning of a related reflex upon extinction varies as the strength of the extinguished reflex. The problem of discrimination is peculiarly concerned with this variation in the extent of the interference.

(XI) Reasons for adopting the method are explained.

APPENDIX I

Deviations of the third order may be regarded as a sort of discrimination in the following way. The rat becomes conditioned not to respond to lever + recent-stimuli-from-ingestion but to respond to lever + recent-period-of-no-responding. Here there are two groups of stimuli possessing the stimuli arising from the lever in common. The differential behavior of the rat may therefore be said to be an example of a discrimination. This is perhaps an adequate description of the behavior, but it is definitely objectionable on systematic grounds, since it requires that an interval of time be regarded as a stimulus, or at least as the differentiating member of a group of stimuli. A stimulus, as an event, takes place in time, but time

alone regarded as a stimulus cannot, of course, have any meaning. The present interpretation of deviations of the third order does not commit this error, since the interval is regarded as one during which an inhibitory state disappears, where the length of the interval is determined by the initial intensity of the state.

In addition to this theoretical objection, the present experimental result leaves no choice between the two interpretations. The development of deviations of the third order, notably in the case of *P7*, is not accompanied by any significant decline in the total slope. This is consistent with the repeated observation that an inhibitory effect is always compensated for by a later period of hyper-activity, but it is directly opposed to the present finding that the development of a discrimination involves an extensive change in rate.

APPENDIX II

Another way of expressing the constancy of the rate assumed under periodic reconditioning is to say that the effect of the reinforcement of a single response is constant. As we have already noted, the number of elicitations observed during the first interval in a series (as recorded, for example, in Figure 2)¹⁸ is obviously less than the number due to the initial reconditioning, since the extinction curve is clearly interrupted; and this is also true for a few succeeding intervals.¹⁹ The rate of elicitation is rapidly accelerated, however, until a given constant rate is attained. If we attribute the acceleration, as we have done, to the eventual appearance of the responses remaining in the interrupted curves, then the attainment of a constant rate must be taken to mean that the number of responses now observed in a single interval is precisely the number due to the reconditioning of one response. The output is just balancing the input, and there are no unexpressed responses to cause further acceleration.

¹⁸This figure is a better illustration than the records for the first day in Figure 3, because the periodic reconditioning is begun in the latter case immediately after the release, and the loss of extinction normally observed at that time tends to obscure the fusion of the separate extinction curves.

¹⁹A response is said to be *due to* previous conditioning in the sense that it would not have been observed if the conditioning had not taken place. We must resort ultimately to a statistical treatment to prove this relation, since a few "investigatory" responses (occurring linearly in time) are present as a base-line. For any reasonable degree of approximation, however, a mere inspection of the present records will suffice. In Figure 1, for example, the relation between the four curves and the times of reconditioning is perfectly clear.

We may represent this relation with the ratio N_e/N_o , where N_e is the number of responses in the extinction curve and N_o the number reconditioned. In the present case the value of the ratio is constant during an extended experimental series. From the data in our possession we can calculate the value when $N_o = 1$. Dividing the total number of responses in each record in Figure 3 (10,700, 3980, 2420, and 2200) by the number of minutes in the series (1440), we obtain average rates of 7.10, 2.51, 1.57, and 1.45 responses *per minute* for rats P7, P9, P8, and P10 respectively. If we now multiply by the number of minutes in the average interval at which each was observed, we obtain 22.8, 16.1, 15.2, and 18.8 as the number of responses *per interval*. In order to take account of uncompleted intervals at the end of each experimental period, we may assume a complete compensation on the following day and obtain another set of values by dividing the total number of responses in each series by the total number of reinforced responses.²⁰ The resulting values are approximately the same: 22.8, 17.4, 15.1, and 18.4. From the first method a mean of 18.2 ± 1.7 is obtained; from the second, 18.4 ± 1.6 . Similarly in the experiment represented in Table 3 we may convert the values for the tangents of the slopes into responses *per hour* by multiplying by 255, the number of responses *per hour* at which the tangent equals 1. This yields 329, 281, 239, and 181 responses *per hour* for the four intervals of 3, 5, 7, and 9 minutes respectively, and dividing by the number of times each interval is contained in 60 minutes, we obtain values of 16.5, 23.4, 27.9, and 27.1 responses *per interval*. It has been noted that the value for the three-minute interval is probably too low and the others too high, and this is in agreement with the mean obtained above. Within rather wide limits, therefore, the ratio is roughly independent of the frequency of reconditioning.

It may be concluded, then, that for every response experimentally reinforced, about 18 will be observed without reinforcement. But this value of the ratio N_e/N_o is not universal. It may hold approximately for the original conditioning of the response, as will be shown elsewhere, but it may also be greatly exceeded in subsequent reconditionings. Furthermore it does not hold when N_o is more than

²⁰There is no reason for subtracting the number of reinforced responses from the total before dividing.

one. Thus if *two* successive responses are periodically reconditioned, the rate of elicitation is increased above that obtained from the reconditioning of one response at the same interval, but it is by no means doubled. This loss in efficiency increases rapidly as N_e increases. The value of the ratio is also certainly dependent upon the degree of hunger present during either the conditioning or extinction (see above), upon the temporal relation of the two processes, and doubtless upon other factors. The relationship is, in fact, even more complex than we have here presented it. In speaking of an N_e/N_o ratio we imply that the curve for extinction is composed of a finite number of responses, although, if our description of the process is essentially correct, this is not true. For certain purposes, however, it is possible to bring the curve to an arbitrary end. But we are then still dealing with only the height of the curve and are neglecting the other information supplied by its shape or the area under it.

Fortunately a description of the relation between what may be called the amount of extinction and the amount of the conditioning to which it is due is not essential to the argument of the paper. This appendix has been included only because the constant rate observed during periodic reconditioning is the clearest indication so far obtained that there is in fact a definite quantitative relation. The indication is clear enough to warrant this tentative general principle: *the total number of elicitations of a given response is limited*. The principle is to a certain extent already implied by the nature of the concept of the reflex (2). Thus, while the elicitation of a response is determined primarily by the presence of the appropriate stimulus, given the latter, it is further controlled by laws the nature of which we have considered elsewhere (2, 3, 5, *et al.*) and of which we are here concerned with several specific examples. It is characteristic of these laws that they establish envelopes, from which the behavior of the rat cannot escape, although it may for many reasons fall short of its maximal development thereunder. In general, the envelopes are experimentally controllable, and in the present special case of conditioning followed by extinction the extent of the envelope for extinction is seen to be determined by the amount of conditioning.

The instances of "overshooting" reported herein and elsewhere (6) may seem to violate this general rule. Consider, for example, the record for *P5* in Figure 12. We have already supposed that

the constant rate maintained on days 1 and 2 in this graph is determined by the balanced input and output obtaining under periodic reconditioning. Now, beginning with day 3 there is no longer any input. Nevertheless, during the first part of this day a much higher rate of elicitation is actually observed. Where are these extra responses obtained?

This question can be answered from the experimental material and the hypotheses already in our possession. We saw above that the constant rate is determined not alone by a mere summation of extinction curves but by the inhibitory effect of the ingestion of food. But no food is ingested during extinction, and the rate of elicitation, free from this restraining effect, may rise above its previous constant value. *Nevertheless*, we must still regard the total slope as a measure of the effect of the reconditioning and any increase above it must be supposed to be a temporary state of imbalance. In other words, the curve for extinction *must* start at the constant slope given during periodic reconditioning. It is significant therefore that the theoretical curves in Figure 12 satisfy this requirement, although the property was not sought in the curve-fitting. According to this explanation the phenomenon should not be observed with the procedure of discrimination, since the inhibitory stimuli continue to be administered. It is apparent from Figure 9 that this is true, since the initial rate during discrimination is the rate previously assumed under periodic reconditioning. Our demonstration of the essential similarity of the properties of the two processes (based as it is upon the end points of the daily records) does not extend to the nature of the daily records themselves or, consequently, to these temporary "strained" states.

Although in this case the overshooting can be attributed to the removal of inhibitory stimulation, it is not possible at present to account for all examples in a similar way. Nevertheless, they can be shown to be exceptional states. In the present case we have demonstrated this by showing a return to a theoretical curve. In other cases of overshooting we can usually show that a record returns to the extrapolation of a curve previously established. It is thus possible, even though a definite cause of a deviation is lacking, to demonstrate that it is only a temporary state of imbalance and thus to preserve the general principle, while admitting occasional violations.

APPENDIX III

The average delay in pressing the lever after the magazine has been connected (see Section IV) should be a function of the rate of elicitation. More exactly it should be equal to one-half the average interval between successive responses, provided the time of connection is wholly independent of the behavior of the rat, and provided the responses to the lever do not occur in groups. Since the second of these conditions is not fulfilled, the observed delays are considerably longer than half the average interval. Table 4 gives the relevant material from the experiment represented in Figure 3. Lines 1-5 are taken from measurements made at the time of the experiment to the nearest five seconds (a closer approximation was impractical at the time). Line 2 is to be preferred to line 1, since a constant rate was not stabilized on the first day. It should be compared with line 7 in estimating the departure from the values to be expected when the above conditions are fulfilled. A progressive shortening of the delay may be observed in a comparison of lines 3, 4, and 5. This is due to the appearance of third-order deviations, which tend to concentrate the responses at the end of the interval, where the reconditioning occurs. The connection of the magazine is then made during a period of relatively rapid responding; and where the third-order effect is pronounced the observed delay may

TABLE 4

	Interval between periodic reinforcements			
	3 min.	6 min.	9 min.	12 min.
1. Average delay for total series in seconds	5.6	26.7	47.0	59.3
2. Average, omitting first day, in seconds	5.0	23.6	40.6	59.6
3. Average for first eight days in seconds	9.5	34.9	67.6	93.5
4. Average for second eight days in seconds	4.6	24.7	38.1	43.6
5. Average for third eight days in seconds	2.8	20.9	37.4	38.0
6. Average rate of responding for total series in responses per hour	446	166	101	92
7. One-half the average interval between responses in seconds (calculated)	4.0	10.9	17.8	19.6
8. Number of delays counted	439	208	136	92

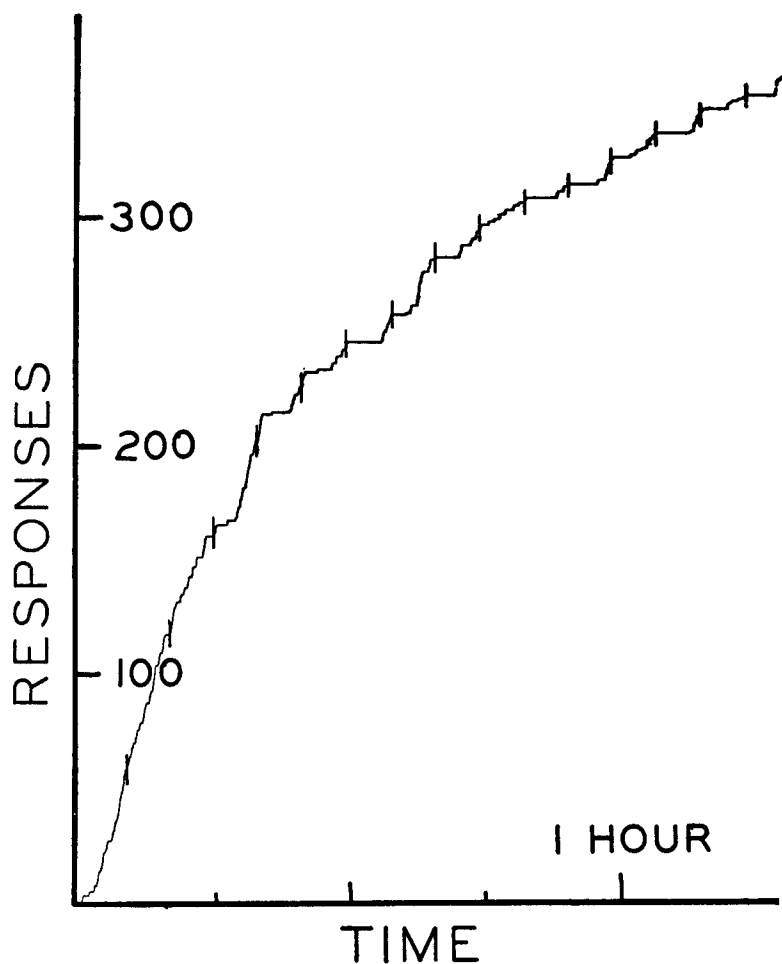


FIGURE 17

CHANGE IN THE SLOPE ASSUMED UNDER PERIODIC RECONDITIONING WHEN THE ADMINISTRATION OF PELLETS IS NOT CORRELATED WITH RESPONSES TO THE LEVER

Pellets are received periodically as usual but no response is reinforced.

become less than that calculated as half the average interval (cf. column 1, lines 3, 4, and 5).

APPENDIX IV

As an extra check upon the present interpretation of a discrimination, we may examine a third case in which the slope established under periodic reconditioning should change in approximately the same way. Let a basic slope be established with any suitable interval of reconditioning. Then let one pellet of food be discharged from the magazine periodically at approximately that interval, but always at a time when the rat is not responding. Then, although pellets are obtained as usual, none of the responses to the lever is actually reinforced. Figure 17 shows the result for the first day of such an experiment. A basic slope had been established with reconditioning at five minutes for a long series of daily experiments. On the day represented in the figure a pellet was discharged from the magazine by the experimenter approximately every five minutes, but never less than fifteen seconds after the last previous response of the rat. A very significant change in slope is apparent.

This is the only example that has so far been obtained with this procedure. The series of which it is the first member could be described with the equation given above, although a single case is hardly convincing. Granting the applicability, however, the series shows a large value for K , which seems to indicate that some reconditioning is effected even though the discharge of the pellet follows the preceding response at a considerable interval.

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LA VITESSE DE L'ÉTABLISSEMENT D'UNE DISCRIMINATION

(Résumé)

Une méthode utilisant la vitesse à laquelle un réflexe se montre sous une stimulation constante comme mesure de sa force pendant les processus du conditionnement et de l'extinction s'emploie dans l'investigation de l'établissement d'une discrimination. Un réflexe arbitraire—la poussée d'un levier en bas par un rat—devient premièrement conditionnel quand la réponse est immédiatement suivie de la mise de nourriture dans un plateau commode et est éteint quand la réponse n'est pas ainsi suivie. Dans le cas présent on conditionne de nouveau le réflexe et l'éteint alternativement en permettant que la réponse ne soit suivie de la mise de nourriture qu'à certains intervalles fixes. Les courbes séparées de l'extinction se combient alors, et le réflexe assume une force constante, qu'il maintient sans une modification significative pendant même vingt-quatre heures expérimentales. La valeur de la force assumée est une fonction de l'intervalle auquel le réflexe devient de nouveau conditionnel. Aux plus hautes vitesses d'établissement (c'est-à-dire, aux plus courts intervalles) la mise de la nourriture inhibe à la longue le réflexe pendant une partie de l'intervalle succédant, mais un effet compensateur fait que le nombre total des réponses reste le même pour chaque intervalle. Dans l'établissement d'une discrimination on introduit un stimulus supplémentaire à chaque nouveau conditionnement mais on l'omet pendant les périodes intermédiaires de l'extinction. La réponse au levier plus le stimulus supplémentaire reste alors tout-à-fait conditionnelle, tandis que la réponse au levier seul s'éteint. La courbe qui décrit ce changement a les propriétés de la courbe normale de l'extinction, dont l'on donne des exemples. Une différence quantitative mesure probablement l'empiètement des deux groupes de stimuli.

SKINNER

DAS MASS FÜR DEN VOLLZUG EINER UNTERSCHIEDUNG

(Referat)

Eine Methode, die die Angaben verwertet, unter denen ein Reflex unter konstanter Reizung zustandekommt, und die als Mass deren Stärke während der Erstellung bedingter Reize und der Auslöschung gelten, wird zur Untersuchung des Unterscheidungsprozesses gebraucht. Ein beliebiger Reflex —das Herunterdrücken eines Hebels durch eine Ratte— wird ursprünglich bedingt, wenn unmittelbar nach der Reaktion Nahrung in einem bequemen Trog verabreicht wird, und ausgelöscht, wenn die Reaktion nicht so befolgt wird. Im gegenwärtigen Fall wird der Reflex abwechselungsweise bedingt und ausgelöscht, indem man der Reaktion nur nach gewissen festgelegten Intervallen Nahrung folgen lässt. Die einzelnen Auslöschkurven verschmelzen dann, und der Reflex nimmt eine konstante Stärke an, die ohne bedeutende Änderungen bis auf 24 Experimentstunden erhalten bleibt. Der angenommene Stärkewert ist eine Funktion des Intervalls, unter dem der Reflex bedingt wurde. Bei höheren Werten der Hervorlockung (d. h. bei kürzeren Intervallen) hemmt die Verabreichung von Nahrung gelegentlich den Reflex für einen Teil der nachfolgenden Intervalle, aber eine Kompensationswirkung lässt die Gesamtzahl der Reaktion pro Intervall unverändert. Während der Erstellung einer Unterscheidung

wird bei jedem Weiderbedingungsvorgang ein Extrareiz eingeführt, der aber während der dazwischenliegenden Auslöschperioden unterlassen wird. Die Reaktion auf den Hebel plus Extrareiz bleiben ganz bedingt, währenddem die Reaktion auf den Hebel allein ausgelöscht wird. Die Kurve, die diese Veränderung beschreibt, hat die Eigenschaften einer normalen Auslöschkurve, wofür Beispiele gegeben werden. Wahrscheinlich ist ein quantitativer Unterschied ein Mass für das Übergreifen der zwei Reizgruppen.

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